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SOVIET ARTICLE ON EXPERIMENTAL INVESTIGATION OF A FLOW-TYPE TEMPERATURE GAUGE IN A HIGH-VELOCITY GAS STREAM

[Comment: The following is the full text of an article by N. V. Ilyukhin and L. N. Naurits, published in the Zhurnal Tekhnicheskoy Fiziki, Vol XXII, No 12, December 1952, pp 2014-2025. Figures referred to are appended. Numbers in parentheses refer to appended bibliography.]

This article presents the results of an experimental investigation of a flow-type temperature gauge with controlled delivery of air through the device; the recovery coefficient of the device is determined and recommendations as to its use are given.

I. GENERAL CONSIDERATIONS

The problem of temperature measurement in a high-velocity gas stream, the principal aspects of the method of the experiment, and the processing of experimental facts have been presented in our previous works.(1, 2)

Here it is necessary only to mention that we accept as the most rational dimensionless characteristic of the temperature gauge the recovery coefficient

$$r = \frac{T' - T}{\theta - T},$$

where T' is the gauge's own temperature, T is the thermodynamic temperature of the current, and θ is the frictional-action [braking] temperature.

The function $r = f$ (M, Re) is investigated during operation with air.

The present article presents the basic results of the experimental investigation of a flow-type instrument. The principle of operation of the instrument investigated is that the junction of the thermocouple in the inner flow duct of the instrument is blown on by a stream of air of moderate velocity, thus creating the conditions for measuring the braking temperature.

A continuous flow of air within the instrument assures a sufficient degree of heat transfer between the stream and the indicator of the device and therefore makes it sensitive. To eliminate errors during measuring due to loss of heat through the walls of the instrument, it is made of material (textolite) of low heat conductivity.

The published results of various other investigators of similar instruments differ.(3, 4) Also, many features of the operation of thermoprobes of this type have not been adequately investigated. In particular, no one has explained the interaction between the thermocouple junction and a stream moving at moderate velocity within the flow part of the instrument.

In some investigations, the operation of flowing around the indicator of the device was influenced by varying the size of the ventilation opening. However, no quantitative relations were established.

Likewise, the influence, on the instrument readings, of the location of the thermojunction along the length of the duct has not been investigated.

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In our latest work, we aimed at a detailed investigation of the properties of the gauge under various gas-dynamic conditions.

In executing the work, we had the following tasks:

1. To establish the influence of air input, flowing through the inner chamber of the instrument, on the gauge's own temperature.

2. To explain the variation of the gauge's own temperature in relationship to the location of the thermojunction within the tip.

3. To determine the influence of the angle of attack.

4. To establish the picture of the variation of the gauge's own temperature when shifting the thermojunction next to the inlet to the flow part of the instrument.

5. To make recommendations about the practical use of flow-type thermoprobes.

The experimental method is described in detail in a previous article.(1)

Characteristic of this method is the shifting of the investigated instrument in an insulated duct. Figure 1 is a diagram of the apparatus. Figure 2 shows the experimental unit with the gauge being investigated.

Description of the Gauge

The investigated probe had four replaceable tips, differing in the length of the cylindrical part (46, 31, 20, and 15 mm). Figure 3 shows one of the tips (length, 31 mm). The design of the probe itself is shown in Figure 4. The probe consists of a body 1, a tip 2 connected to the body by means of a threaded joint (the tip being cylindrical in form and 4 mm in internal diameter), and a hollow holder 3 whose duct serves as an outlet for air from the instrument. A copper-constantan thermocouple 4 with 0.3-mm diameter is located within the flow part of the tip.

The design of the instrument provides for shifting the thermojunction along the length of the duct. For this purpose, a small piston 5 has been placed within the body of the instrument; the thermocouple is passed through the piston and fastened to it. The steel wire 6, one end of which is attached to the piston and the other end of which is attached to the carriage of a micrometer slide caliper, permits shifting the piston along the axis of the instrument. The steel spring 7 provides the return motion of the spring. The micrometer slide caliper reading fixes the position of the thermojunction to an accuracy of 0.1 mm.

To ascertain the dependence of the instrument readings on the angle of attack, the probe has been made rotatable about an axis perpendicular to the direction of the stream, the axis of rotation being the geometrical axis of the holder which rotates together with the gauge. The angle of rotation is read on a special scale with the aid of a pointer fastened to the holder. Also provided for was a means for varying the input of air, flowing through the inner chamber of the instrument, independently of the velocity of the inflowing stream. The input of air passing through the inner part of the instrument was measured by means of a rheometer.

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II. RESULTS OF THE RESEARCH

Effect of Air Input on Gauge's Own Temperature

The investigation was conducted with a tip 46-mm long. The thermojunction was placed on the axis in the center of the cylindrical part of the inner duct of the tip.

Experiments were conducted at three different velocities of the inflowing stream: 197, 230, and 256 m/sec, which correspond to the following values for Re and M of the main stream: $Re = 2.92 \cdot 10^5$; $3.52 \cdot 10^5$; $4.03 \cdot 10^5$; and $M = 0.58_3$; 0.69_3; 0.78_5.

The results of the experiment are represented by curves in Figures 5 and 6.

Figure 6 shows that in all three cases the dependence of the recovery coefficient of the instrument on the input of air through the gauge, i.e., on Re_{meas}, was of like character.

The value Re_{meas} was determined according to the formula

$$Re_{meas} = \frac{4G_{meas}}{\pi d_{meas} \mu\theta},$$

where G_{meas} is the input of air through the inner chamber of the thermoprobe; d_{meas} is the internal diameter of the tip; $\mu\theta$ is the kinematic viscosity of the air at the braking temperature.

At very small values of air input through the gauge ($Re_{meas} = 1.5 \cdot 10^3$), the difference $(\theta - T')$ between the braking temperature and the measured temperature increased (up to 0.6 - 1.0 deg C approx) and correspondingly the recovery coefficient of the instrument decreased to 0.96 - 0.97. Increasing the air input ($Re_{meas} \approx 7.0 \cdot 10^3$) causes at first a rapid and then a slower decrease in the temperature difference $\theta - T'$ (correspondingly, increase of the recovery coefficient). Further $\theta - T'$, and consequently r also, maintain constant values up to Re_{meas} of the order of $13.0 \cdot 10^3$.

Thus, the most suitable conditions for the operation of the instrument were at Re_{meas} values from $6.5 \cdot 10^3$ to $13 \cdot 10^3$. Under these conditions the recovery coefficient of the instrument has a stable value of the order of 0.99.

Variation of the Gauge's Own Temperature in Relationship to Location of the Thermojunction

Experiments were conducted with tips 46 and 31 mm in length. As already stated, the design of the instrument permitted shifting the thermojunction along the length of the internal duct.

The variation in the temperature difference $\theta - T'$ and the recovery coefficient r in relationship to the position of the thermojunction in the duct of the 46-mm tip is shown in Figure 7. The variation of air input through the experimental unit ranged from G = 385 kg/hr up to G = 648 kg/hr, corresponding to values of Re from $2.95 \cdot 10^5$ and M from 0.58_0 to 0.77_8.

At the same time, the air input through the inner chamber of the instrument varied within the range of Re_{meas} values from $7.1 \cdot 10^3$ to $11.8 \cdot 10^3$, thus remaining within the range of values corresponding to the most advantageous conditions of flow around the thermojunction.

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Figure 8 shows the relationship of the temperature difference $\theta - T'$ and the recovery coefficient to the position of the thermojunction within the duct of the 31-mm tip. The experiments were conducted at two values of air input through the experimental unit: 547 and 400 kg/hr at corresponding Re values $4.32 \cdot 10^5$ and $3.15 \cdot 10^5$ and M values 0.8_0 and 0.58_4. In each experiment, the input of air through the thermoprobe was kept steady; at the greater input, the Re_{meas} values reached $9.4 \cdot 10^3$, and at the lesser input $Re_{meas} = 8.6 \cdot 10^3$.

An examination of the experimental data indicates the constancy of characteristics of the instrument during shifting of the thermojunction from the inlet to the center of the duct. In proportion to the further shifting of the junction deeper within the instrument, after it has passed the mid-point of the duct there is a noticeable although slight tendency towards an increase in the temperature difference and a decrease in the recovery coefficient. Thus, for example, the lower curve of Figure 7 shows that the variation in temperature difference $\theta - T'$ at the 15-mm length reaches, on an average, 0.20°C. This circumstance can be explained by the following considerations.

The temperature of the outer wall of the instrument differs from the braking temperature (the greater the velocity of the incoming stream the greater the difference), owing to the incompleteness of recovery $[r<1]$. A change in the velocity of the outer stream and in the recovery coefficient along the length of the tip leads to the formation of a heterogeneous temperature field of the outer surface of the instrument. The temperature of the inner wall of the duct is nearer to the braking temperature since the stream of air within the device has a low velocity and a temperature practically equal to the braking temperature. Under the influence of the temperature gradient directed from the inner wall to the outer, a heat exchange develops, the intensity of which increases with an increase in velocity of the inflowing stream. Consequently, the difference between the braking temperature and the gauge's own temperature depends (although admittedly only to a very slight degree) on the velocity of the inflowing stream and the location of the thermojunction.

Actually, all the experiments of this series indicate the tendency (weak, but indisputable) toward a decrease in the recovery coefficient in proportion to the shift of the thermojunction from the mid-point of the duct to a point deeper within the duct. This decrease is so quantitatively insignificant that, for practical purposes, the recovery coefficient may be considered constant.

Relationship of Recovery Coefficient to Velocity of Inflowing Stream

The results of the experiments with replaceable tips 46, 31, 20, and 15 mm long are given below.

In all the experiments, the hot junction of the thermocouple was situated at about the mid-point of the length of the duct of the tip.

The input of air through the gauge was maintained within the range which guaranteed the most favorable conditions of flow about the thermojunction.

The main results from the processing of the experimental data are given in the following table.

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Length of Tip	Range of Velocity Variation in the Considered Section	Range of Variation of Values			Values of the Recovery Coefficient
l(mm)	w(m/sec)	$M = \frac{w}{a}$	$Re = \frac{4}{\pi g d}\frac{G}{\mu\theta}$	$Re_{meas}\ \frac{4}{\pi g d_{meas}}\ \frac{G_{meas}}{\mu\theta}$	$r = \frac{T' - T}{\theta - T}$
46	170-270	0.[illegible]-0.82	$2.5\cdot10^5$-$5.4\cdot10^5$	$6.5\cdot10^3$-$9.1\cdot10^3$	0.98_6
31	150-270	0.44-0.82	$2.4\cdot10^5$-$6.5\cdot10^5$	$6.5\cdot10^3$-$11.0\cdot10^3$	0.99_5
20	160-260	0.47-0.80	$2.5\cdot10^5$-$5.3\cdot10^5$	$6.9\cdot10^3$-$9.5\cdot10^3$	0.99_5
15	150-280	0.44-0.87	$2.5\cdot10^5$-$5.2\cdot10^5$	$6.7\cdot10^3$-$9.4\cdot10^3$	0.88_5-0.99_5

The relationship of the recovery coefficient to the M value for a thermoprobe with tips of different lengths is shown in Figure 9.

As is evident, the experimental points lie closely about the straight line $r = 0.99$. The deviations of the values for r obtained in experiments with different tips do not exceed ± 1 percent: actually, for tips 46, 31, and 20 mm long, the average value for r is equal to 0.98_6, 0.99_5, and 0.99_5, respectively. Only in the experiments with the 15 mm-long tip is there detected an insignificant increase of the recovery coefficient with an increase in the M value (during the change in the M value from 0.44 to 0.87, the recovery coefficient increases from 0.98_5 to 0.99_5).

Thus, an increase in the length of the tip of the instrument within the range 15-46 mm does not lead to a noticeable change in the recovery coefficient of the thermoprobe.

Influence of Angle of Attack

The main conclusion, toward which the results of research on this problem lead, is that the thermoprobe of the type investigated is insensitive to small changes in the angle of attack which could occure as a result of inaccuracies of adjustment of the instrument.

As an illustration, we cite the results, presented in Figure 10, of the tests of the thermoprobe with a tip 31 mm long. This tip permitted a change in the angle of attack of ± 13 degrees. The thermojunction at this time was located 15 mm from the mouth of the duct of the instrument. The experiments were conducted at two inputs of air through the experimental unit: 568 kg/hr and 383 kg/hr, which correspond to the Re values $4.34 \cdot 10^5$ and $2.93 \cdot 10^5$, and to the M values 0.79_1 and 0.55_9.

The results cited actually show that the investigated thermoprobe is insensitive to a change in the angle of attack within the limits of ± 13 degrees.

Instrument Readings With Pointer Placed in Inflowing Stream

An instrument which has a stable value for the coefficient of recovery independent of the location of the junction in the duct loses this property when the junction is led out from the inner cavity into the stream, and becomes quite sensitive even to extremely small displacements of the junction.

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To investigate this phenomenon, special tests were conducted in which the thermojunction was not only shifted within the duct of the tip, but was also moved out of the instrument directly into the inflowing stream. This series of tests was conducted with two tips, 31 and 20 mm long. The results of the experiment are presented in Figures 11 and 12.

With the 31 mm-long tip, tests were conducted at two velocities of the inflowing stream: 163 m/sec and 257 m/sec, with respective Re values $2.68 \cdot 10^5$ and $4.66 \cdot 10^5$, and respective M values 0.48_9 and 0.79_7. The input of air through the gauge correspond to the Re_{meas} values $7.2 \cdot 10^3$ and $9.3 \cdot 10^3$. The thermojunction, initially placed in the duct of the instrument at a distance of 15 mm from the entrance, was gradually shifted in the direction of the inlet and then moved out beyond the edge of the instrument itself directly into the inflowing stream. In its extreme position, it was moved out of the duct of the instrument to a distance of 8 mm.

The shifting of the thermojunction outside the instrument in the inflowing stream was accompanied by a sharp increase in the temperature difference $\theta - T'$ from 0.1 to 2.4°C at an inflowing-current velocity of 163 m/sec and from 0.3 to 5.7°C at w = 257 m/sec; correspondingly, the coefficient of recovery decreased from 0.99 to 0.82 and from 0.99 to 0.83.

The test with the 20 mm tip was conducted at an inflowing-current velocity of 245 m/sec at Re value $3.89 \cdot 10^5$ and M value 0.75_5. The input of air through the instrument corresponded to the value $Re_{meas} = 9.0 \cdot 10^3$. The thermojunction was shifted in the stream, gradually moving away from the inlet cross section of the instrument to a distance of 11 mm.

As in the preceding test, the shifting of the junction outside the instrument, directly in the inflowing stream, was accompanied by a significant increase in the temperature difference $\theta - T'$ (from 0.3°C in the inlet cross section to 5.4°C in the extreme position), which caused a reduction in the recovery coefficient from 0.99_5 to 0.82_0.

Thus, the results of the tests attest to the change in temperature difference $\theta - T'$ and, consequently, the recovery coefficient, in relationship to the displacement of the thermojunction outside the instrument itself.

In all cases, the zone of marked variation in the temperature difference $\theta - T'$ is limited to a 5-mm distance from the inlet cross section of the instrument. On farther removal of the thermojunction from the inlet cross section of the instrument toward the stream, the change in the temperature difference $\theta - T'$ is noticeably retarded and, at a distance of 10 mm. practically ceases; the difference $\theta - T'$ reaches a constant value for the given conditions.

The marked worsening of the properties of the instrument during removal of the thermojunction from the inner chamber into the inflowing stream is explained by the fundamental change in the operating conditions of the indicator. From the case where the thermojunction is passed by a stream of moderate velocity in the inner cavity of the instrument, we pass to the case where it is passed by an inflowing stream of air of high velocity. This explanation is practically confirmed by the full agreement of the attained results with the data of our tests on the study of the properties of transversely streamlined bare thermocouples.(5) For illustration, we present in Figure 13 the curve of the relationship $r = f(M)$ taken from the article just mentioned.

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Figures 12 and 13 show that the recovery coefficient of a transversely streamlined thermocouple with a 0.3-mm diameter, at an M value of the inflowing current equal to 0.76, has the value r = 0.82. Exactly this value for the recovery coefficient of the thermoprobe is obtained under analogous conditions (M = 0.76 and a thermoelement diameter of 0.3 mm) on removal of the junction to a distance of 11 mm from the inlet of the instrument.

Comparison With Results of Other Investigations

In Figures 14, 15, and 16, the results of the present work are compared with the data of other investigations.(3, 4) A comparative analysis of the curves shows that the thermoprobe investigated in the present work has the highest and most stable value for the recovery coefficient. The influence of the angle of attack within the range of ± 12 degrees is not disclosed in any of the other investigations.

In Zysina's test, the recovery coefficient of the instrument attains a stable value (but not exceeding 0.93) on increasing the M value of the inflowing stream to 0.7 and higher. A decrease in the value of M leads to a drop in r approximately down to value 0.7 — 0.8. The instability of the recovery coefficient with a change in the value of M apparently can be explained by a not altogether successful selection of the ratios of the areas of the ventilation openings. This should show an especially strong effect on the conditions of interaction of the thermojunction with the air stream, braked in the inner chamber of the instrument, at low velocities of the inflowing stream. These very principles explain a certain instability of the recovery coefficient of the instrument in the tests of Hottel and Kalitinskiy and led to a drop in r at a decrease in velocity of the inflowing stream. A comparison of the results of these tests with the data of the present work is given in Figure 15.

The stable value of the recovery coefficient, obtained during tests of a thermoprobe of the design under investigation, is explained by better conditions of flow about the junction which were assured by the correct selection of air input through the inner chamber of the instrument. By means of a device for regulating the input of air through the inner chamber of the instrument, it proved possible to conduct serial tests on the establishment of the relationship $r = f(M)$ in the self-modeling (relative to Re_{meas}) field.

CONCLUSIONS

As a result of the investigations, the following conclusions can be made.

1. The recovery coefficient of the thermoprobe through a broad range of variation of the M value from 0.45 to 0.97 at a variation of the Re value from $2.4 \cdot 10^5$ to $6.5 \cdot 10^5$ maintains a constant value which is near unity (0.99).

2. The recovery coefficient primarily depends on the conditions of flow about the thermojunction within the instrument, which are characterized by the value of Re_{meas} (in our investigations from $6.5 \cdot 10^3$ to $13.0 \cdot 10^3$).

3. A higher and more stable value for the recovery coefficient of the investigated instrument in comparison with the results received by other investigators depends on the rational selection of the input of air through the inner chamber of the instrument and the correct location of the thermojunction in this chamber.

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4. Special tests have shown that the junction should not be placed next to the inlet section of the instrument. Placing the junction in the rear half of the instrument also is not recommended. The junction should be placed in about the middle of the duct, slightly nearer the inlet.

5. The recovery coefficient of the thermoprobe practically does not depend on the accuracy of adjustment of the instrument as regards the inflowing stream. In our experiments, a variation in the angle of attack within the range ± 13 degrees did not show any noticeable influence on the readings of the instrument.

6. An increase in the length of the tip of the instrument within the range from 15 to 46 mm does not lead to a noticeable change in the recovery coefficient of the thermoprobe. It should be mentioned, however, that for the 15-mm-long tip there was a certain tendency toward an increase in the recovery coefficient during an increase in the value of M.

7. Thermometric flow-type probes can be recommended as gauges in a high-velocity gas stream. To create more favorable operating conditions for the instrument indicator, it is necessary to maintain a ratio between the areas of the inlet and outlet cross sections which assures a Re_{meas} value of the order of $10 \cdot 10^3$ (from $6.5 \cdot 10^3$ to $13.0 \cdot 10^3$).

8. The present work studied the effects which develop as a result of the interaction of solid body with a high-velocity stream of gas under conditions of adiabatic flow. By its very concept, the stating of the experiment excluded the influence of radiation exchange. This permitted the reliable study of the hydrodynamic and heat effects developing in a high-velocity stream. The use of flow-type thermoprobes largely excludes the influence of radiation, since the tip of the instrument consists of a single shield. However, if necessary, use of a double, flow-type shield is possible. (This, of course, leads to a certain complication in the design of the instrument.)

Engineer A. F. Gandel'sman and technician A. S. Prostakova participated in conducting the tests.

In conclusion, the authors wish to express their thanks to Prof A. A. Gukhman for valuable advice which helped them in this work.

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16 July 1952

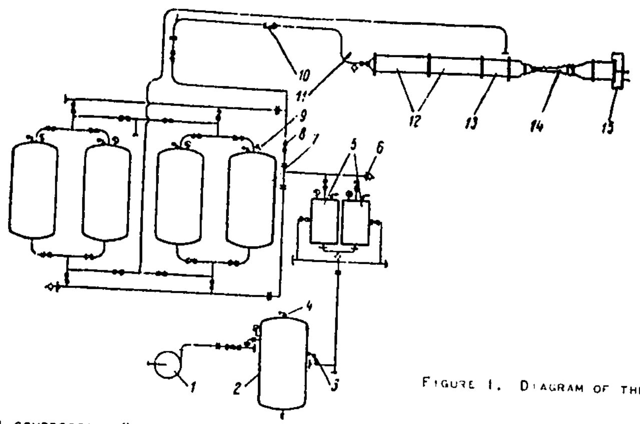

Figure 1. Diagram of the Apparatus

1 compressor, 2 receiver, 3 valve, 4 safety valve, 5 oil separators, 6 end cap, 7 air dryer, 8 valve, 9 manometer, 10 nozzle for measuring air input, 11 thermometer, 12 air heater, 13 mixer, 14 experimental unit, 15 counterpressure chamber

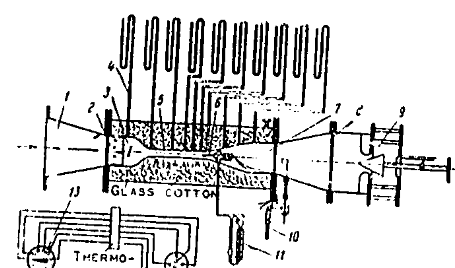

Figure 2. Diagram of the Experimental Unit

1 conical transition, 2 temperature adapter, 3 inlet zone, 4 V-shaped manometer, 5 cylindrical zone, 6 temperature probe, 7 outlet zone, 8 conical transition, 9 counter-pressure chamber, 10 micrometer slide calipers, 11 rheometer, 12 valve for regulating input of air, 13 mercury switch

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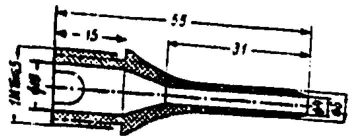

Figure 3. 31-Millimeter Tip

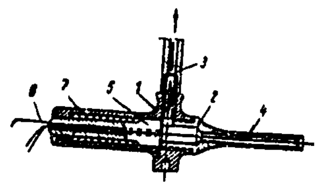

Figure 4. Temperature Probe Under Investigation

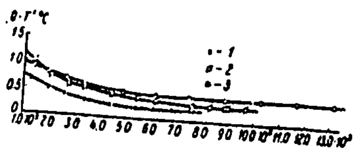

Figure 5. The Influence of the Air Input Through the Gauge on the Temperature Difference θ—T' (tip 46 mm long)

1. W = 197 m/sec, Re = 2.94 · 10^5, M = 0.58; 2. W = 230 m/sec, Re = 3.54 · 10^-5, M = 0.69; 3. W = 256 m/sec, Re = 4.03 · 10^-5, M = 0.78

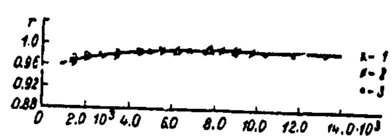

Figure 6. Relationship of the Recovery Coefficient to Re_{meas} (tip 46 mm long)

The points 1, 2, and 3 obtained under the same conditions as in Figure 5.

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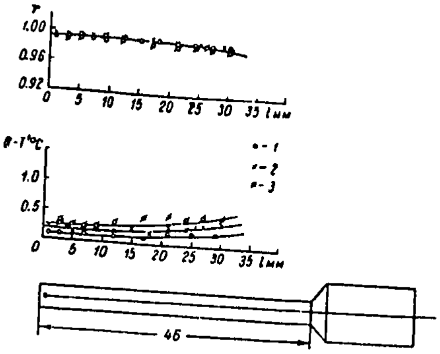

Figure 7. Relationship of the Temperature Difference Θ—T' and the Recovery Coefficient to the Location of the Thermojunction in the Duct (tip 46 mm long)

1. w = 196 m/sec, Re = $2.95 \cdot 10^5$, Re_{meas} = $7.1 \cdot 10^3$; 2. w = 230 m/sec, Re = $349 \cdot 10^{-9}$, Re_{meas} = $8.9 \cdot 10^{-3}$; 3. w = 256 m/sec, Re = $4.92 \cdot 10^5$, Re_{meas} = $10.9 \cdot 10^5$

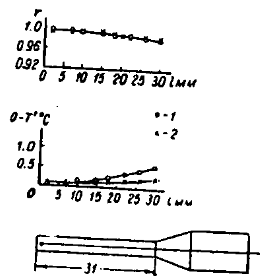

Figure 8. Relationship of the Temperature Difference Θ—T' and the Recovery Coefficient to the Location of the Thermojunction in the Duct (tip 31 mm long)

1. w = 256 m/sec, Re = $4.32 \cdot 10^5$, Re_{meas} = $9.4 \cdot 10^{-3}$, M = 0.80; 2. w = 192 m/sec, Re = $3.15 \cdot 10^{-5}$, Re_{meas} = $8.6 \cdot 10^{-3}$, M = 0.58

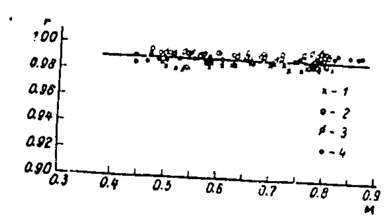

Figure 9. The Relationship of the Recovery Coefficient to the M Value for the Thermoprobe With Tips of Various Lengths

1. l = 46 mm, Re_{meas} = $8.0 \cdot 10^3$; 2. l = 31 mm, Re_{meas} = $9.0 \cdot 10^3$; 3. l = 20 mm, Re_{meas} = $8.9 \cdot 10^3$; 4. l = 15 mm, Re_{meas} = $8.73 \cdot 10^3$

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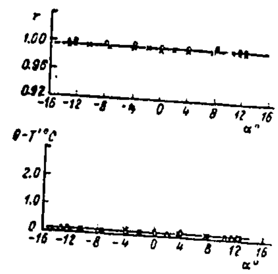

Figure 10. The Influence of the Angle of Attack on the Recovery Coefficient for the 31-Millimeter-Long Tip

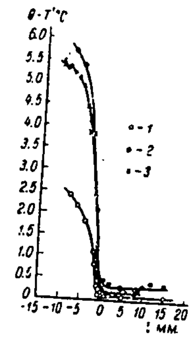

Figure 11. Curves of the Temperature Difference θ—T on Removal of the Thermojunction Into the Inflowing Stream, for Tips 31 and 20 Millimeters Long

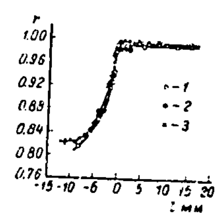

Figure 12. Curves of Recovery Coefficient Variation on Shifting the Junction Into the Inflowing Stream, for Tips 31 and 20 Millimeters Long. Points 1, 2, and 3 obtained under the same conditions as in Figure 11.

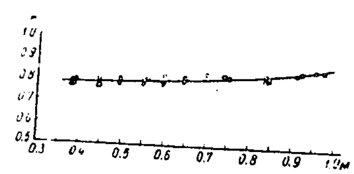

Figure 13. Relationship of the Recovery Coefficient of the Transversely Streamlined Thermocouple With a Diameter of 0.3 Millimeters to the M Value

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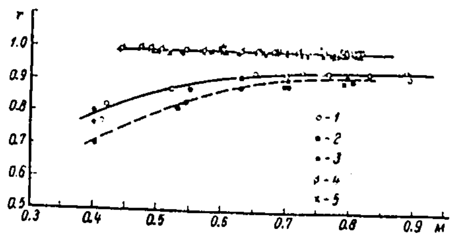

Figure 14. Comparison of the Characteristics of the Investigated Thermoprobe and the Thermoprobes Tested by Zysina.

1, 2, 3. Tests of Zysina-Molozhen: 1. Pitot tube-type thermometer, 2. cylindrical thermometer, 3. diffusion thermometer; 4, 5. Our tests: 4. gauge with tip 31 mm long, 5. gauge with tip 46 mm long

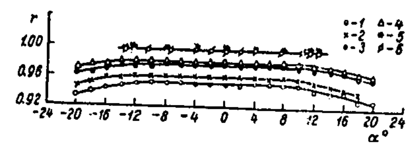

Figure 15. Comparison of the Curves of the Relationship of the Recovery Coefficients of the Instrument to the Velocity of the Inflowing Stream, Obtained by Various Investigators

1. Frants-type probe of reduced dimensions, 2. Pratt and Whitney probe, 3. "MOT," 4. gauge with tip l = 46 mm, 5. gauge with tip l = 46 mm

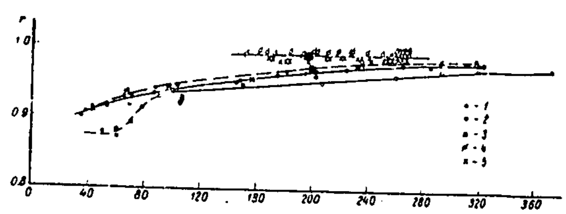

Figure 16. Comparison of Data on the Influence of the Angle of Attack on Thermoprobe Readings According to the Investigations of Hottel and Kalitinskiy and According to the Results of the Present Work.

1-4. From data of Hottel and Kalitinskiy: 1. 130 m/sec; 2. 181 m/sec; 3. 287 m/sec; 4. 317 m/sec. 5, 6. From data of the Moscow Branch of the Central Scientific Research Boiler and Turbine Institute: 5. 258 m/sec; 6. 188 m/sec

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